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ORIGINAL RESEARCH

MODIFYING STANCE ALTERS THE PEAK KNEE ADDUCTION MOMENT DURING A GOLF SWING

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ABSTRACT

Background: The knee joint is one of the most frequently injured regions in the game of golf, and the loads experienced by the knee during the golf swing are typically greater than during other activities of daily living. Altering movement patterns is a common strategy that can be used to reduce loading on the knee joint but has received little attention during studies of the golf swing. The primary aim of this study was to examine the effect altering golf stance has on the lead limb peak external knee adduction moment.

Study Design: Laboratory based, quasi-experimental

Methods: Twenty healthy participants were recruited for a 3-dimensional biomechanical analysis wherein participants hit three golf shots with a driver using the following stance conditions: self-selected, bilateral 0° foot angle, bilateral 30° foot angle, wide stance width, and narrow stance width.

Results: Both the 30° foot angle (0.80 $\pm$ 0.51 Nm) and wide stance width (0.89 $\pm$ 0.49 Nm) conditions significantly decreased ($p < 0.001$) the lead limb peak external knee adduction moment compared to the self-selected (1.15 $\pm$ 0.58 Nm) golf stance. No significant differences ($p = 0.109$) in swing speed were found between any of the stance conditions.

Conclusion: The externally rotated foot position and wider stance width decreased the lead limb peak external knee adduction moment without hindering swing speed. Modifying stance could be a viable option for golfers who wish to continue playing the sport at a high level, while reducing potentially detrimental loads at the knee joint.

Levels of Evidence: 2b-Individual cohort study

Keywords: Biomechanics, golf, injury, knee, osteoarthritis

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INTRODUCTION

Golf is a popular sport played by roughly 55 million individuals.[1] Considering its perceived low impact nature and aerobic exercise component, golf is widely recommended by medical professionals for patients wishing to remain active in the later stages of life.[2,3] However, previous research indicates that up to 72% of golfers have experienced an injury, suggesting there is potential for strain on the musculoskeletal system during the golf swing.[2-7] Specifically, the knee joint is one of the most frequently injured regions.[2,4,6] The forces and moments experienced by the body during the golf swing are not believed to be of sufficient magnitude to cause acute injury, but it is possible that chronic abnormal loading may lead to knee injury.[6,8] Since golf is a popular choice of exercise for many individuals, interventions to reduce potentially harmful loading of the knee may expand the longevity of one's playing career.

The external knee adduction moment has traditionally been used as a surrogate measure of the distribution of forces between the medial and lateral compartments of the knee joint.[9,10] Previous researchers have shown a strong association between a high peak external knee adduction moment during gait and the presence, progression, and pain of medial compartment knee osteoarthritis (OA).[9-11] Furthermore, knee joint loading may be of interest to a golfing population since forces have been reported to be substantially larger during the golf swing than various activities of daily living (i.e. walking, stair ascent, and stair decent).[12,13] Therefore, strategies to reduce the peak external knee adduction moment during the swing may be helpful in terms of lowering the risk of the development or progression of knee OA in golfers.

Altering movement patterns has been used effectively to reduce loading on the knee joint during gait. Specifically, adaptations such as increasing one's self-selected foot angle (internal/external rotation of the foot) or stance width have both been shown to decrease the peak knee adduction moment during gait.[14-18] Indeed, Lynn et al.[12] reported a reduction in the peak external knee adduction moment when both feet were externally rotated 30º, compared to 0º (feet perpendicular to target line). Considering golfers do not typically stand with a 0º foot angle, comparing the peak knee adduction moment during altered stances in relation to a golfer's self-selected stance may give a more realistic representation of the potential reductions in loading. Also, no researchers have examined the effects of altering stance width on the peak external knee adduction moment during the golf swing. Since a wider stance width has been shown to decrease the knee adduction moment during gait, the strategy may also result in beneficial reductions of the moment during the golf swing.

Although altering stance has been shown to decrease loading at the knee,[12] manipulations to a golfer's stance may have implications on performance.[19-21] Swing speed is a relatively simple marker of performance since it is strongly correlated with total driving distance.[22] Therefore, when considering alterations to swing technique, it is pertinent to examine whether they have negative implications for swing speed.

In summary, there is limited research exploring strategies to reduce the external knee adduction moment during the golf swing. Therefore, the primary aim of this study was to examine the effect altering golf stance has on the lead limb peak external knee adduction moment. It was hypothesized that increasing foot angle and/or increasing stance width of a golfer's stance would significantly decrease the peak external knee adduction moment. The secondary aim of this study was to examine the effect that the previously mentioned stance alterations have on swing speed.

METHODS

This was a laboratory based, quasi-experimental study design. The independent variables include foot angle (self-selected, 0º, and 30º) and stance width (self-selected, narrow, and wide). The dependent variables were the golfer's lead limb peak external knee adduction moment and swing speed at impact.

All participants had to be between the ages of 18-55 with a USGA golf handicap of 20 or below. Participants were excluded if they: were unable to perform multiple golf swings without pain or injury; had undergone orthopedic surgery; had current or previous injuries that limited golf activity in the prior three months; or exhibited any physical or medical problems for which exercise would be contraindicated. The study was approved by the University of Kentucky Institutional Review Board and all participants provided informed consent.

The final sample included 20 healthy volunteers, 16 males (age: 26.3 $\pm$ 6.5 yrs, height: 1.79 $\pm$ 0.07 m, mass: 83.6 $\pm$ 10.6 kg, USGA Handicap: 11.6 $\pm$ 5.7) and four females (age: 25.3 $\pm$ 10.6 yrs, height: 1.65 $\pm$ 0.05 m, mass: 60.1 $\pm$ 5.4 kg, USGA Handicap: 4.6 $\pm$ 9.6). Participants wore a standardized neutral shoe (Nike Xccelerator TR, Beaverton, OR) in their own size for the entire data collection. Using double sided adhesive tape, fifty-seven reflective markers were placed on the participant's skin or shoe over the following anatomical landmarks: bilateral acromion process, sternal notch, spinous process of the seventh cervical vertebrae (C7), spinous process of the twelfth thoracic vertebrae (T12), bilateral iliac crest, bilateral ASIS & PSIS, bilateral greater trochanter, bilateral medial & lateral knee, bilateral medial and lateral malleoli, bilateral lateral heel, bilateral proximal & distal heel, bilateral 1st & 5th metatarsal head, bilateral third toe, and a offset marker on the right foot. Lastly, rigid body clusters of four markers were placed on the anterior/lateral aspect of the subject's right shank and left thigh/shank, while five markers were used on the right thigh.

Participants were given the option to use one of four drivers for the data collection: left or right men's Callaway X Series (10.5 loft, standard length, and stiff flex shaft) and left or right women's Callaway X Series (10.5 loft, standard length, and ladies flex shaft). Participants were asked to address the golf ball with their normal (self-selected) golf stance while a pen was used to mark the ground next to the heel and third toe of each foot. The investigators then drew a line representing the longitudinal axis of the foot in the transverse plane (this represented the self-selected stance position). This line was subsequently used to create additional markings, enabling the participants to alter their foot angle (while keeping stance width constant) and stance width (while keeping foot angle constant). Stance width was defined as the distance between the centers of the heels. Following a brief warm up period (approximately five minutes of practice swings and drives), participants were asked to hit three golf drives using each of the following stance conditions: self-selected, 0° (both feet oriented perpendicular to target line), 30° (both feet externally rotated from 0°), 20% narrower (than self-selected), and 20% wider (than self-selected) (Figure 1). The order of the stance conditions was block randomized. Participants were allowed rest as needed between each of the various trials, and a short acclimation period was given during the transition to each stance position. Three-dimensional marker co-ordinate data were collected for both a static standing trial and the dynamic golf swing trials using ten high speed cameras (Motion Analysis Corp, Santa Rosa, CA) at a sampling rate of 200 Hz. A SC100 radar device (Voice Caddie Corp, La Mirada, CA) was placed two meters behind the golf ball to measure swing speed. Kinetic data for the lead limb was collected at 1000 Hz using a force plate (Bertec Corporation, Columbus, OH).

Marker trajectory data were tracked using Cortex software (Motion Analysis Corp., Santa Rosa, CA), while further data processing was conducted using Visual 3D software (C-Motion Inc., Germantown,

Figure 1. *Experimental setup for dynamic golf swing trial.*

MD). Raw marker trajectory data were filtered using a fourth order low-pass Butterworth filter with a cut-off frequency of 12 Hz. The cut-off frequency was determined by use of a residual analysis.[23] An X-Y-Z Cardan sequence (sagittal-frontal-transverse) was used to quantify joint angles, in which the distal segment was expressed relative to the proximal segment.[23,24] An adapted version of the model from Nesbit et al.[24] was utilized for the lower extremity kinematic and kinetic calculations. Discrete variables of interest included the lead limb peak external knee adduction moment. The peak external knee adduction moment was determined by the greatest value observed between the top of the backswing and the finish of the golf swing. Lastly, top of backswing and finish events were used to time normalize data, and an ensemble mean value for three consecutive golf swings was calculated for each subject for each of the five stance conditions.

STATISTICAL METHODS

Repeated measures ANOVA analyses were used to determine if there were differences in the peak external knee adduction moment and swing speed between the stance conditions. A planned contrasts analysis was used to determine which (if any) stance conditions were significantly different from the self-selected condition at an alpha level of $p < 0.05$. Furthermore, Pearson product-moment correlations were performed to determine if the magnitude of change in the external knee adduction moment was related to how much a participant altered their foot angle or stance width from their self-selected position. Specifically, correlations were performed between: i) the change in foot angle vs. the change in the peak external knee adduction moment between the self-selected and 30º foot angle conditions, ii) the change in stance width vs. the change in the peak external knee adduction moment between the self-selected and wide stance width conditions. All statistical analyses were performed using SPSS 24 statistical software (SPSS Inc., Chicago, IL).

RESULTS

Descriptive statistics for the peak external knee adduction moment and swing speed for all stance conditions are presented in Table 1. The ensemble mean curves of the peak external knee adduction moment are shown in Figure 2, which demonstrates that the peak moment occurred just after impact. On average, the participants addressed the ball with a self-selected foot angle of 11.3 ± 5.3º external rotation and stance width of 0.49 ± 0.07 meters. The peak external knee adduction moment was significantly different ($p < .001$) between the five stance conditions (Table 1). The planned contrasts analyses revealed both the 30º foot angle and wide stance width conditions significantly decreased the peak external knee adduction moment ($p < .001$) when compared to self-selected. In contrast, the narrow stance width condition significantly increased ($p = .023$) the peak external knee adduction moment when compared to self-selected. No significant differences ($p = 0.605$) were found in the peak external knee adduction moment between the 0º and self-selected foot angle conditions. Furthermore, a weak correlation was found between the change in foot angle vs. the change in the external knee adduction moment ($r = -.228$, $p = 0.333$) and the change in stance width vs. the change in external knee adduction moment ($r = .040$, $p = 0.866$) (Figure 3). In terms of the secondary aim there were no significant differences ($p = .109$) in swing speed between any of the stance conditions (Table 1).

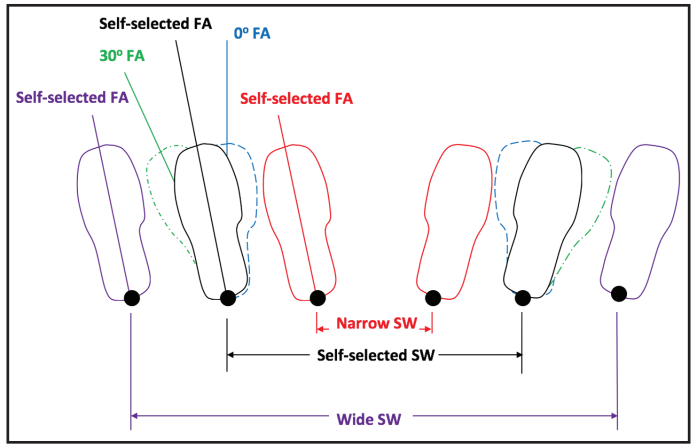

Figure 2. *Experimental setup: self-selected, bilateral 0° foot angle (FA), bilateral 30° foot angle, narrow stance width (SW), and wide stance width.*

DISCUSSION

The primary aim of this study was to examine the effect of altering golf stance on the peak external knee adduction moment. The hypothesis was confirmed in that both the 30º foot angle and wide stance width

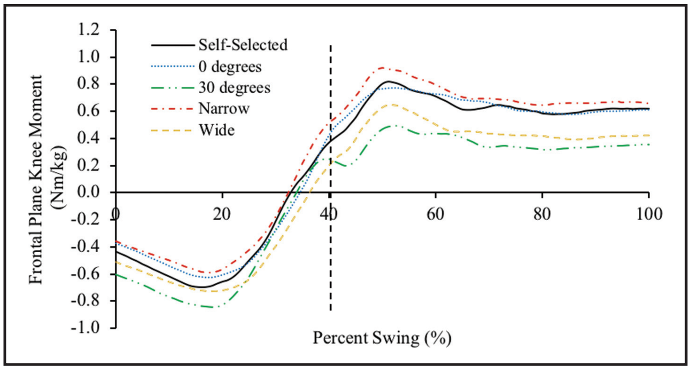

Figure 3. *Ensemble mean of frontal plane moments for lead limb knee joint. Percent swing is normalized from "top of backswing" (0%) to "follow through" (100%) events. Vertical dashed line represents "impact".*

Table 1. *Mean (95% Confidence Interval) for peak knee adduction moment and swing speed for golf stance conditions.*

Stance Condition	Peak Knee Adduction Moment (Nm/kg)	Swing Speed (mph)
Self-selected	1.15 (0.90-1.41)	98.87 (94.25-103.48)
0 degree	1.12 (0.89-1.36)	97.90 (93.33-102.47)
30 degree	*0.80 (0.58-1.03)	98.30 (93.98-102.62)
Narrow	*1.23 (0.98-1.48)	97.30 (93.18-101.42)
Wide	*0.89 (0.67-1.11)	98.53 (93.87-103.20)

*Significantly different from self-selected (p<0.05)

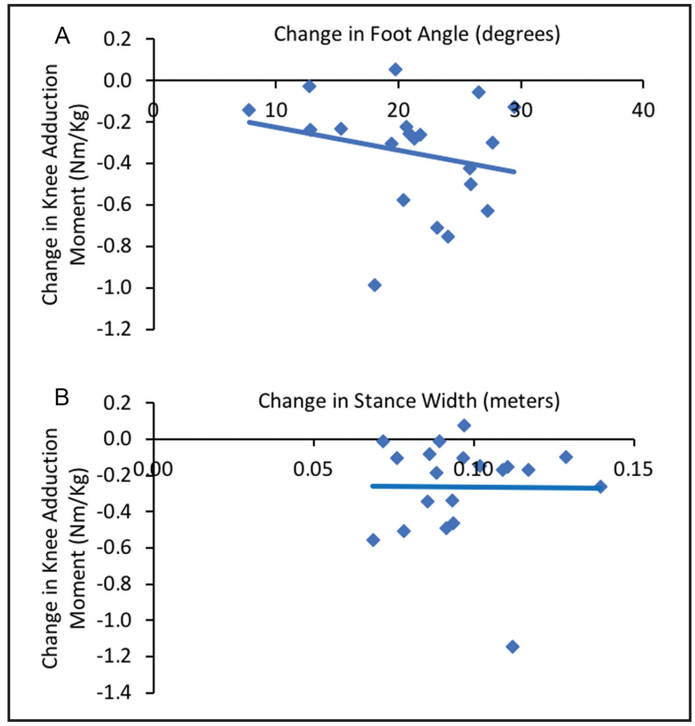

Figure 4. *Relationship between A) change in foot angle vs. the change in the peak knee adduction moment (self-selected vs. 30° foot angle); B) change in stance width vs. the change in the peak knee adduction moment (self-selected vs. wide stance width).*

conditions significantly decreased ($p < .001$) the peak external knee adduction moment when compared to the self-selected stance. Moreover, 19 and 18 out of the total 20 golfers reduced their peak external knee adduction moment when altering stance to the 30° foot angle and wide stance width conditions respectively. Although previous literature has also reported a reduction in the peak knee adduction moment when the feet are placed in greater external rotation, the magnitude of the change differed slightly from current findings. Specifically, Lynn et al.[12] found a 14.3% reduction in the peak external knee adduction moment when the feet were externally rotated 30°, while the current study found a 30.4% reduction between the 30° and self-selected conditions. One possible explanation for the greater reduction of the knee moment in the present study is that the participants used a driver whereas Lynn et al.[12] utilized a 5 iron. Given the expected greater exertion when using a driver, the potential reductions in knee loading with an externally rotated foot position may be greater than previously reported.

To the authors' knowledge, this is the first study to examine the effect of stance width on the peak external knee adduction moment during the golf swing. However, present findings mirror the trends reported during gait modification studies. Specifically, Favre et al.[16] and Fregley et al.[17] found 17.1% and 9% reductions in the peak knee adduction moment respectively when participants widened their stance during walking, while the current study results demonstrated a 22.6% reduction between the wide and self-selected stance width conditions. In addition, Favre et al.[16] found a 13.7% increase in the peak knee adduction moment in gait when participants utilized a narrow stance width, while present data suggest a 6.9% increase between narrow and self-selected stances during the golf swing. Given the external knee adduction moment is larger during the golf swing in comparison to walking, a 22.6% reduction in the peak external knee adduction moment during the golf swing would correspond to an even larger reduction in the absolute moment than those reported in walking.

Although the 30º foot angle and wide stance width conditions successfully reduced loading at the knee, the magnitude of the change in the external knee adduction moment seemed unrelated to the amount that individuals altered their stance parameters (foot angle or stance width). For instance, participants in this study addressed the golf ball with a range of self-selected foot angles (1.1-23.5º) and stance widths (0.36-0.64 m), thus requiring individuals to change their foot angles and stance widths to varying extents to achieve the appropriate modification. However, the weak correlations indicated that individuals with a greater change in foot angle or stance width did not necessarily have a greater reduction in loading at the knee. It is possible that the poor relationship may be partially explained by individual differences in anatomical alignment such as knee varus/valgus, tibial torsion or femoral retro/anteversion, which may cause golfers to respond differently to the stance modifications.

Although this study was conducted using healthy individuals, the findings may also have clinical implications for populations who have, or are risk of developing medial compartment knee OA. It has been widely proposed that reducing the external knee adduction moment may in turn reduce loads placed on the medial compartment knee joint.[9-12,14] Therefore, reducing the external knee adduction moment has become a common strategy to not only slow the development/progression of medial compartment knee OA, but also alleviate symptoms from the disease.[9-12,14] The findings of the present study suggest that adopting an externally rotated foot position or wider stance width may potentially be beneficial to golfers with medial compartment knee OA or those at risk of developing the disease. However, further research is necessary to confirm whether similar reductions in the external knee adduction moment can be achieved by players afflicted with knee OA. More importantly, the effect that the proposed stance modifications have on knee OA related pain must also be tested.

Both males and female participants were included in this study. Although previous literature indicates potential differences in swing kinematics between genders, the results from the current study show the systematic change in the peak external knee adduction moment between stance conditions was similar for males and females.[25] Specifically, males experienced 29% and 23% reductions in the external knee adduction moment during the 30º and wide stance conditions respectively, while females experienced 35% and 23% reductions in loading for the equivalent conditions. Also, a similar increase in the peak external knee adduction moment was observed in males (5%) and females (16%) for the narrow stance width, when compared to a self-selected stance width. Therefore, an externally rotated foot position or wider stance width can be used to decrease the peak external knee adduction moment in both males and females.

The secondary aim of this study was to analyze the effect altering a golfer's stance had on performance. Golf performance has been previously broken down into two components; distance and accuracy. For this study, only swing speed was analyzed since it has been strongly associated to total distance.[22] Current results found no significant differences in swing speed between the five stance conditions, thus indicating the alterations in stance did not hinder the ability for the golfer to generate maximum swing speed. Furthermore, the authors believe that the previously mentioned stance conditions will not prevent a golfer from hitting the golf ball his or her maximum distance potential. This suggests that the externally rotated foot position and the wider stance were both successful in terms of decreasing the peak external knee adduction moment without hindering performance, by a measure of swing speed.

This study contained a few limitations. Firstly, swing speed was the only variable used to assess performance. Measuring driving accuracy in addition to swing speed may provide a more complete picture as to how altering a golfer's stance effects performance. Therefore, future researchers should assess both swing speed and accuracy as performance variables. Secondly, all data collections were performed in a laboratory environment. Therefore, results cannot account for external factors such as surface condition (i.e. grass or sand), surface grade, and the interaction between the surface and shoe which all typically vary during a round of golf.

CONCLUSIONS

The results of the present study indicate that an externally rotated foot position or a wider stance width decreased the lead limb peak external knee adduction moment when compared to a self-selected golf stance. The non-significant changes in swing speed between stance conditions suggest the previously mentioned alterations in stance may be used to decrease joint loading without hindering the golfer's ability to generate maximum swing speed. Therefore, adopting a 30° foot angle or a wider stance width may be viable options for golfers to reduce potentially harmful loads at the knee joint and help them continue playing the sport at a high level. In particular, the findings may have clinical implications for those individuals who are at risk of the development or progression of medial compartment knee osteoarthritis.

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